AN ILLUSTRATED HISTORY OF MINING and METALLURGY

by

H. H. Manchester

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Mining in America, from title page of De Bry

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Prefatory Note by J. E. Spurr

THE interesting series of illustrated articles by Mr. Manchester, which was published in Engineering & Mining Journal-Press, and is reprinted in this booklet, does not pretend to be complete or systematic. They are very valuable for making available to us scattered pictorial and other records which mainly are to be found only in rare old books, mostly lodged at present in museums and a few great libraries. Mr. Manchester has selected four typical periods—the Egyptian period, that of the Greeks and Romans, the Middle Ages in Europe, and in sixteenth century America; and has compiled much picturesque and informative material concerning each. The record stops short there. The work is essentially antiquarian and fragmentary; it is historical rather than technical. The reader will piece out from his own knowledge and from current and available literature the marvelous development of mining and metallurgy since the early Spanish days in America.

An Illustrated History of Mining and Metallurgy

I. In Ancient Egypt

Records in the Form of Drawings and Writings Indicate Ancient Egyptians Conducted Mining and Smelting in a Manner Comparable to Advances in Other Industries—Mine Map Made in Time of King Seti I Earliest Known

THE earliest records of mining antedate even the dawn of civilization. One reason for this is that the prehistoric Egyptians buried various weapons and utensils in their graves, probably with the idea that they would be of assistance to the spirit in the hereafter. In the earliest prehistoric graves are found copper harpoons, chisels, and pins, the heads of which were formed by simply rolling over the shank. Somewhat later, but still in the prehistoric age, daggers and spearheads, also made of copper, were buried with the body. From about the same period, about six thousand years ago, came relics of gold, silver, and lead. Electrum has been discovered in tombs of the First Dynasty. This was no doubt a natural mixture of gold and silver such as came from the Nubian mines.

In prehistoric times it was already discovered that some copper ores, with the imperfect method of smelting then employed, produced a harder metal, and one better suited for tools, than others. Some of the earliest prehistoric tools were hardened through the presence of about 4 per cent arsenic in the metal, and in others this effect was produced by as little as 1 per cent of bismuth. A bronze rod was discovered in a mastaba or tomb, of the Third Dynasty of Meydum, but specimens

Smelting, beating, and weighing in the old Empire of Memphis

of bronze from this period are too rare and questionable to prove that the amalgamation was then known.

A few relics of iron, likewise, have been unearthed among the remains of the Old Kingdom of Memphis, but they are so scarce as to prove that if iron were known at all in that era its use was exceedingly rare.

The greatest supply of copper seems to have come from the Sinai Peninsula, to the east of Egypt. The mines were worked at certain times, though probably not regularly, as early as the First Dynasty, but they were opened up more extensively by King Snefru in the Third Dynasty, and he was afterward looked back upon as the great patron of mining there. A number of the roads leading to Sinai, and stopping places on the way, were named after him, and he was honored along with the god Hathor as the protector of miners.

Much of the mining at Sinai was done by expeditions which were dispatched from Egypt to work during the most favorable months and then return. A proof of this is the inscription left on the rocks by a leader of such an expedition in the Fifth Dynasty. At about this period the mines of Sinai began to be

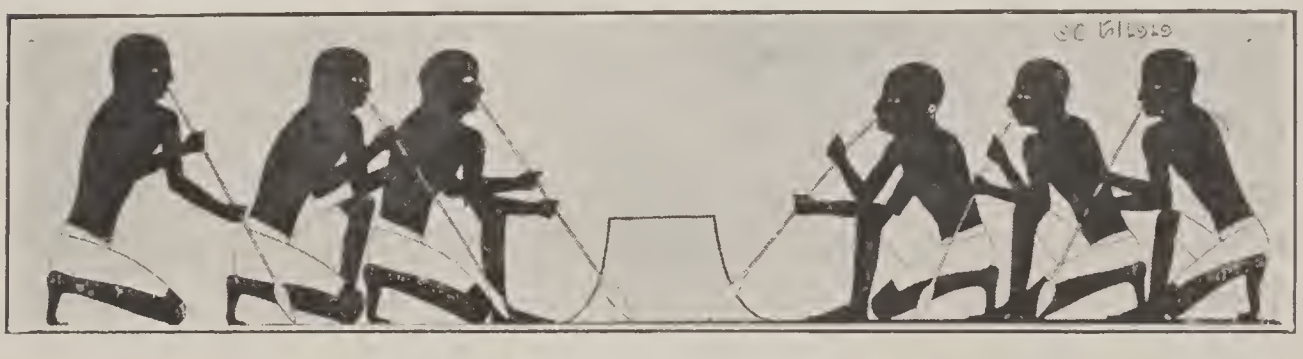
Smelting, in small crucibles, from a tomb of the Sixth Dynasty

Casting in Eighteenth Dynasty

worked for turquoise. This was highly valued in Egypt and was the object of various expeditions. An inscription of that dynasty mentions that the god had caused precious stone to be found in the secret mine, which probably refers to turquoise.

The earliest Egyptian mining tools discovered are stone picks, flint and stone chisels and scrapers, wooden mallets, and stone hammers. The mallet was the shape of a policeman's club; that is, all handle with no head; the hammer, on the other hand, was only a semi-globular piece of stone, thus being all head and no handle. When copper came in it was used for chisels and hammers. The skill of the Egyptians with such rude tools is evidenced in the work they did.

There is no Egyptian account of smelting dating from the Old Empire of Memphis, but several pictures from that period suggest how it was done. In a tomb of the Fifth Dynasty at Sakkara, the ore is apparently in a crucible in the midst of the fire. Around this are sitting several workmen in whose hands are long tubes through which they are blowing the fire. A



An Ancient Egyptian battery of blowpipes

somewhat similar tomb painting at Sakkara illustrates not only smelting the ore but casting and hammering the metal. In both of these pictures the fire was unprotected from the wind, but there was also a small furnace which was like a pot, with one side of the rim raised as a guard against the wind. In this furnace charcoal was burned, and it was probably used for small

The small furnace long continued to be used for gold

amounts of gold. A picture of it represents a workman with a short blow pipe in one hand and a pair of spring-backed tongs in the other.

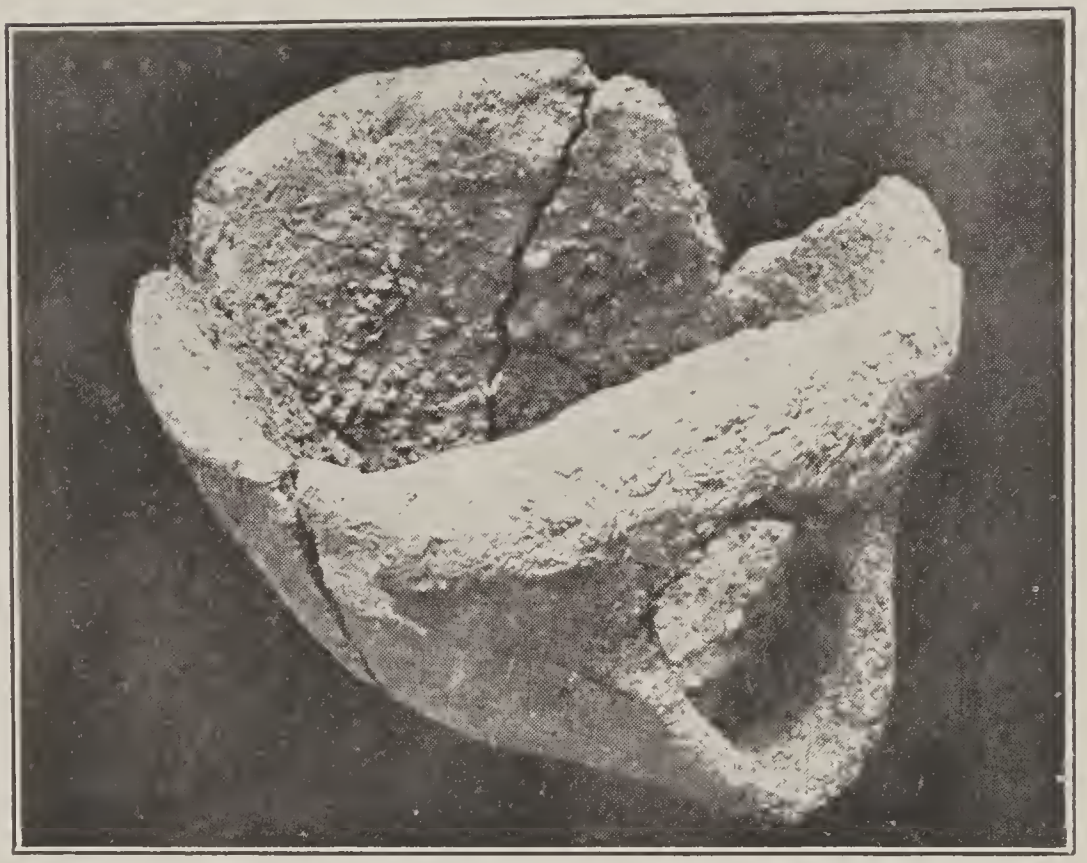
Few records have been found in Egypt from the Sixth to the Eleventh dynasty. But in the Twelfth Dynasty, more than four thousand years ago, mining operations in Sinai were again resumed.

The road to Sinai was no doubt dangerous because of the heat, and the operations themselves might be interrupted by accidents. On this subject we find Sabek-hir-hab congratulating himself in an inscription: "I hollowed out a mine chamber for my king, and the full number of my youths returned; none among them perished. . . . Give praise to the king, the mountains yield what is within, and the hills proffer their riches." The leader of the expedition was commanded to bring back a certain quantity of turquoise, and perhaps copper, and in

carrying out the work he divided his force into gangs of five, with foremen and superintendents. An inscription of Amenenhat in the Twelfth Dynasty declares: "I arrived at the mine of Ka; I procured the quota of turquoise, being . . . for each five men each day. Never had so much been done since the days of the king of Upper and Lower Egypt, Snefru the blessed."

Rock drilling in Egypt 3,500 years ago. Note the position of the workmen and the prod of the foreman

Some of the difficulties met by the expeditions are suggested by an inscription by Harurre, who entered Sinai during the hot season. "I came to the district in the third month of the second season, although it was not the season for travel to the mine-land. . . . The treasurer of the god said: 'Let not your face flinch on this account; behold Hathor will turn it to advantage.' I looked to myself and considered when I came from Egypt. My face flinched and it was difficult for me. The plateaus are parched in summer, and the mountains sear the skin. . . . When I asked the workmen about it they said. 'There is turquoise in this mountain forever,' which was pleasant to hear coming at this season. I began to work fortunately. My force arrived in full numbers; none among them perished; my face recoiled not before the undertaking. I succeeded in mining the best stones, and completed the work in the first month of the



A pottery crucible for copper, from Sinai

Stone pounders for crushing stone, from Sinai

Ancient Egyptian quarryings in a mine in Sinai

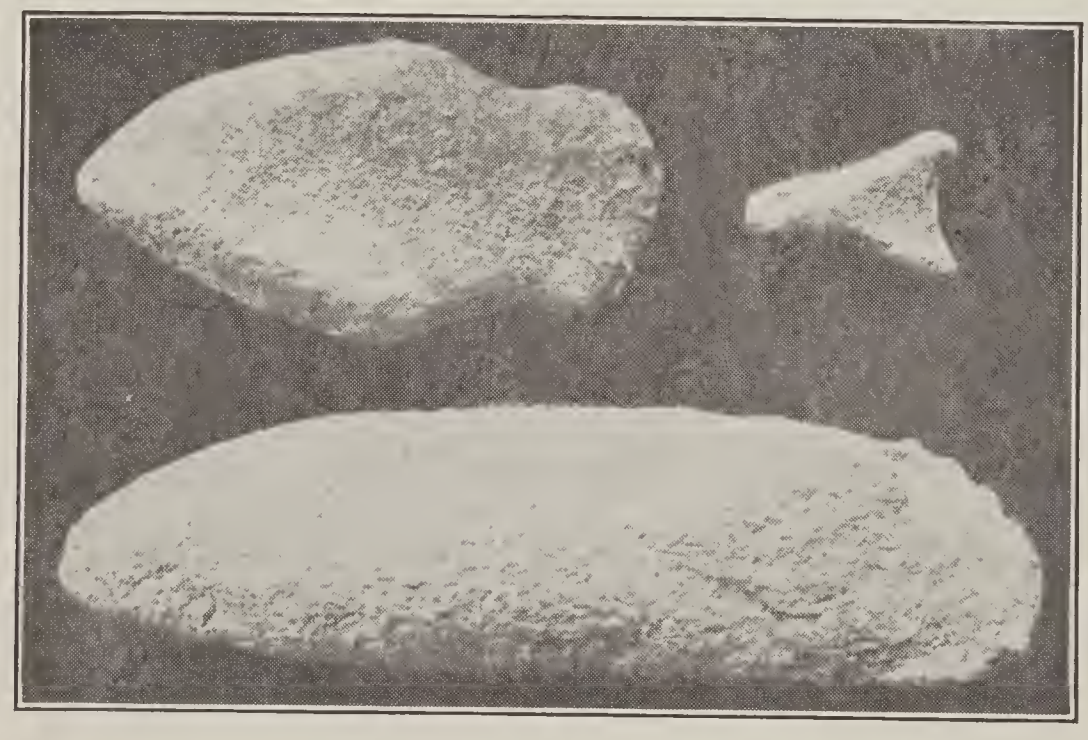
Stone pillars left in mine in Sinai

third season. I brought back genuine precious stones, more than anyone who had come here, and more than the quota; even better than in the usual season. . . . I led my force very considerately, nor was I harsh voiced to the workmen."

The principal sources of gold in early Egypt were probably Nubia and Coptos. In the Twelfth Dynasty Ameni describes the southern expedition for it as follows: "I sailed southward to bring gold ore for the king of Upper and Lower Egypt. . . . I sailed with 400 of my best troops, all of whom returned in safety, without the loss of a man. I brought the quota of gold commanded me, and was praised for it in the palace." Ameni also went on an expedition for gold ore to Coptos, and recorded the event as follows: "To bring gold ore I sailed south to the city of Coptos, together with the hereditary prince, commander of the city and vizier, Sesostris. I sailed south with 600 from the bravest of the Oryx nome. I returned in safety, my soldiers having suffered no loss: I accomplished all that had been commanded me."

In both of these cases, it will be noted that the expedition went after and brought back gold ore, rather than refined gold.

After the Nomadic kings had been driven out of Egypt, and the New Empire of Thebes established, about 3,500 years ago,



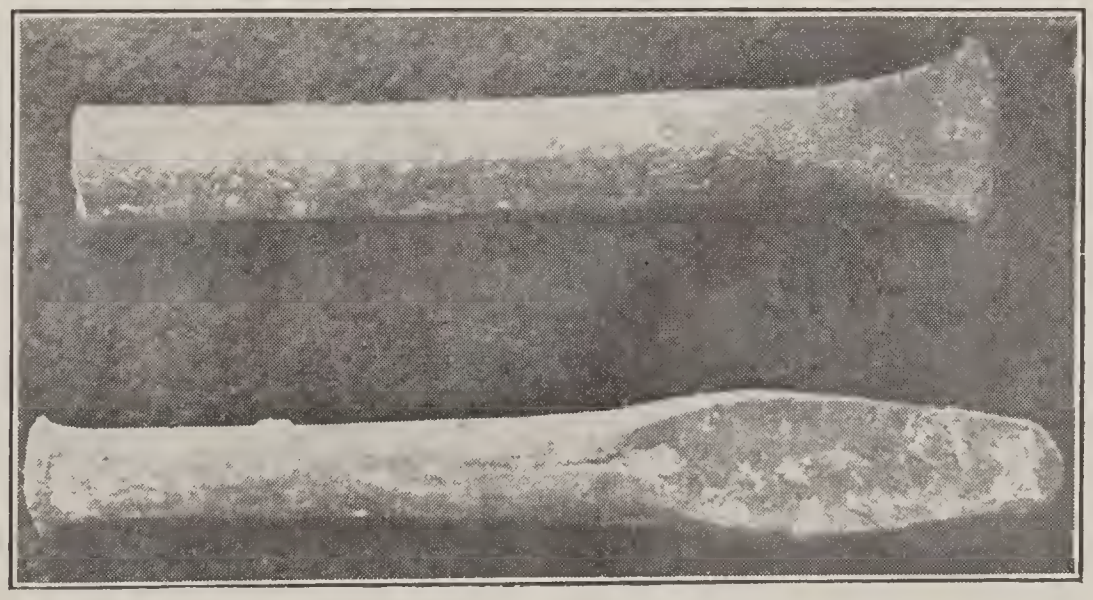
Stone picks from Sinai

an invention was made which greatly facilitated smelting. This was the application of foot power to the bellows. This bellows consisted of a goat skin, with a tube leading from it to the fire. The illustration shows the workman standing with each foot on a skin. By resting his weight on one foot, he drives the air from that bellows into the fire, while by lifting the other skin with a cord he causes it to be filled with air. This was a great improvement over the old blowpipe, and made it possible for the Egyptians to smelt more refractory ores, and in much greater amounts.

In this period bronze became common, though tin for it had to be imported mostly through the Phoenicians. Iron also came into more frequent use, though it was never employed by the Egyptians as much as bronze.

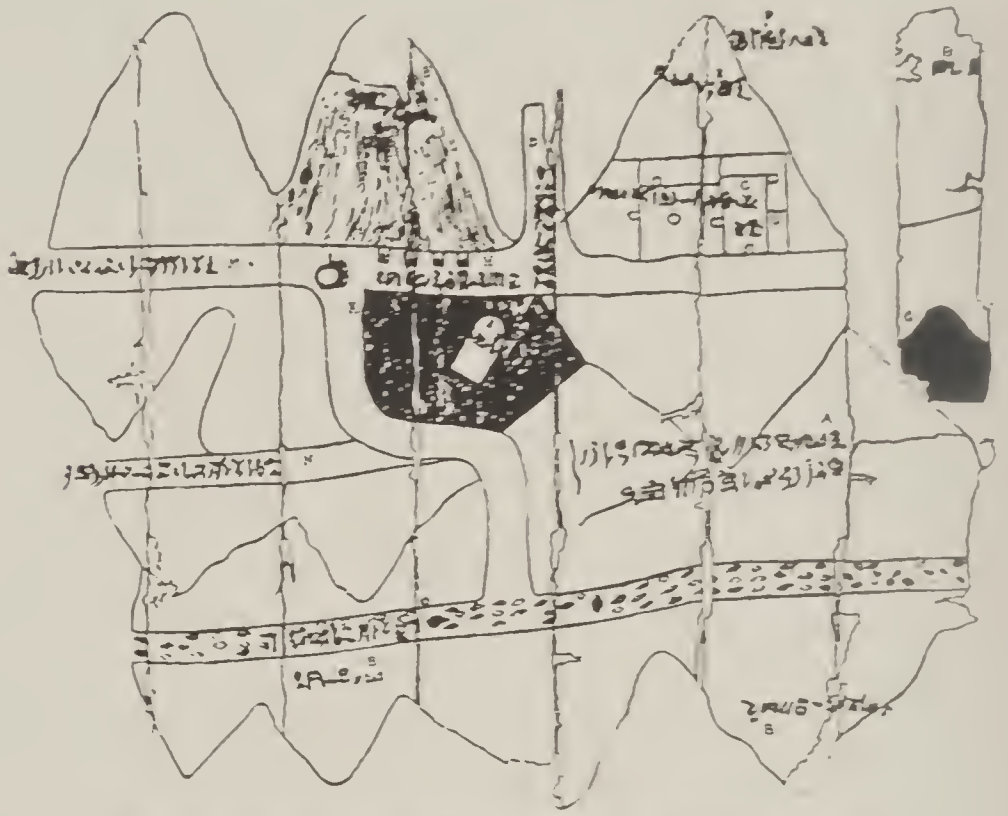
The gold mines of Atika were situated far across the burning desert, and the expeditions were greatly hampered by the absence of water. When Seti I inspected the mines from which electrum was brought, he sorrowed over the lack of water on the way, and caused a well to be dug, which for a time was a great aid to the expeditions. Later this well dried up, and another one was excavated on the road to Akita by Rameses II in the Nineteenth Dynasty.

A remarkable papyrus of that period contains perhaps the oldest plan of a mine in existence. It represents two valleys



Copper chisels for mining, from Sinai

running parallel to each other between the mountains, and united by a winding valley which crosses them. The pointed mountain marked "A" has the notation, "Mountains where gold is washed," while on the mountain marked "B" are the words "gold mine." The valley "M" and the pass "N" are called routes to the sea. On the mountain marked "C" was a temple of Amon. The huts marked "H" no doubt belonged to



An ancient Egyptian map of a gold mine district—
the earliest known map of a mine

the gold miners, while the reservoir marked "K" was probably the well of King Seti I.

In the next dynasty we read of a great expedition sent by Rameses III to the copper mines in Atika: "I dispatched my forces to the land of Atika, to the great copper mines there. Some we carried by galleys, while others went by land upon their asses. The like had not been heard of before since the first kings. The mines were found rich with copper. It was loaded by myriads into the galleys, which were sent on to Egypt and arrived in safety. The bars of copper were brought and piled into a heap under the balcony, a hundred thousand in number."

A similar expedition was sent by Rameses III to the turquoise

mines of Sinai, and brought back genuine turquoise in numerous sacks, as well as silver and gold.

In his researches in Sinai, Petrie found stone picks, pounders, mallets and hammers, as well as flint scrapers for grubbing out the sandstone. A highly interesting relic was a crucible of pottery in the shape of a hemisphere with the rim rising vertically still higher, and the spout considerably below the rim. It is thought that the handle of this was not strong enough to bear

Smelting with foot bellows, Eighteenth Dynasty

the weight of molten metal, and that it was emptied by being rolled rather than lifted.

At the bottom of some of the many huts were buried household utensils of stone or pottery which were too heavy in proportion to their value to be carried back to Egypt, and were hidden by the last occupant of the hut on the chance that he might return.

A thousand years later, after Egypt had been conquered by Alexander, and was under the rule of the Ptolemies, which, it must be remembered, was a Greek dynasty, the old Egyptian system of working the mines through expeditions was changed. The mines were put under close control, and were worked by criminals whose offences were great enough to be punished by life imprisonment. In many cases even their families were ban-

ished to the mines with them, and also forced to wear their lives out at the work.

The mines were visited by Diodorus Siculus in the first century B. C., and he gives something of an account of the methods in use.

The soil was naturally black, but in the body of the earth ran many veins shining with white marble and glistening with all sorts of bright metals. There was one overseer for the whole work, who marked out the stone and showed the laborers what to do. The rock which was the hardest and full of gold, was softened by putting fire under it, and then worked out with the hands. Several thousand wretches followed the vein, and broke it in pieces with hammers and iron pickaxes. They carried lamps fastened to their foreheads to give them light, but otherwise worked in perfect darkness. The pieces of stone were thrown out upon the floor of the galley, where they were gathered up by little boys and carried out.

Other criminals who were about thirty years of age took this rock and pounded it with iron pestles in stone mortars until the pieces were about the size of a bean. The older men and women then placed them in mills and ground them until they were as fine as meal. Finally the masters of the work took the powdered stone and spread it upon a broad and slightly hollowed plank where they washed and cleansed away the earth, the gold, on account of its weight, remaining behind. After washing several times, they drew out the remaining dross by delicately applying slender sponges. Finally, other workmen put it into earthen jars, and, in proportion to the quantity, mixed with it "some lead, grains of salt, a little tin, and barley bran." Covering the pots very tightly, and daubing them over with clay, the men placed them in a furnace and left them there five days and nights, after which, assures Diodorus, only pure refined gold remained.

II. The Greek and Roman Periods

Methods of Pumping Said to Have Been First Developed When Romans Conquered Carthage—This Period Also Marks First Reference to Contract Work—Pliny Wrote Fully Concerning Methods of Mining Gold in First Century

GREEK relics of copper, gold, and silver may be traced to the prehistoric period, but illustrations and accounts of actual mining do not begin until a later date.

One of the earliest and certainly one of the most interesting Greek pictures of mining is a scene in colors on an archaic

A primitive Greek mine. From an archaic Corinthian plate. Note the lamp

Corinthian pinax, which may be dated about 600 B. C. This depicts an excavation about eight feet in depth and about the same in width. A miner is attacking one side with a pickaxe, while a boy is gathering up the lumps dislodged and handing them to a woman who is kneeling over the top of the excavation. This may well portray mining by a family at a time when the mines in Greece were still so undeveloped as to require only the simplest operations. One noteworthy detail is a good-sized

lamp which is hung above the working place and furnishes light in addition to that from the opening to the sky.

In the early period, the mines which are mentioned are described as exceedingly rich, but probably only the most readily extracted richer ore was taken out. Herodotus, who wrote about 500 B. C., stated that in Siphnos, "there were mines of gold and silver of so rich a yield, that from a tenth of the ores, the Siphnians furnished out a treasury at Delphi, which was on a par with the grandest there. What the mines yielded was divided year by year among the citizens."

Xenophon wrote that the mines of Laurion had been worked from time immemorial. In a treatise on the revenues, he discloses several facts as to the method of working mines which are of interest. "It is an old story," he declares, "how formerly Nicias owned a thousand men in the silver mines, whom he let out to Sosias, a Thracian. Sosias was to pay him a net obol (3c.) a day, without charge or deduction for every slave of the thousand and keep up that number continuously. So also Hipponicus let out 600 slaves which brought him a net mina ($20) a day." Thus it appears that from a very early period the mines at Laurion were worked by slave labor.

Modern excavations at Laurion have revealed narrow galleries winding into chambers which are in part supported by pillars of stone which have either been left standing or put together for the purpose. A small, partly destroyed furnace has also been discovered, which, it is thought, was used in freeing the silver from the lead.

Much richer than the mines of Laurion were those of Spain. According to Diodorus Siculus, the Pyrenees Mountains were so called because at one time in the distant past they had taken fire, and continued burning for a long time. This had melted so much silver that the metal had flowed down in streams. Since the use of this was unknown to the inhabitants, the Phoenicians had obtained it for mere trifles, and after loading their ships as full as possible, they had even cut the lead weights from their anchors and substituted silver.

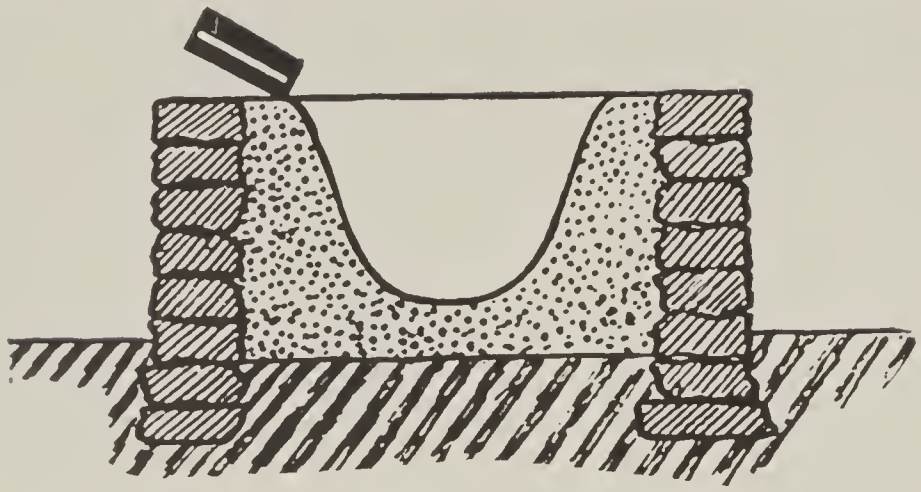
Supports in a gallery in Laurion

At first anybody might collect the precious metals, and even common laborers in silver mines earned good wages.

After the Carthaginians conquered the country, they made a search for the precious ores, and opened up so many mines that but few new ones were discovered afterward. It was the silver and gold from these mines which they used to pay the mercenary troops that formed so large a part of the Carthaginian armies.

When the Romans conquered Carthage and took possession of Spain they developed the slave and contract system of working the mines. The slaves followed the veins from where they cropped out at the surface far into the mountains. By

An ancient Greek miner and his ax-like pick



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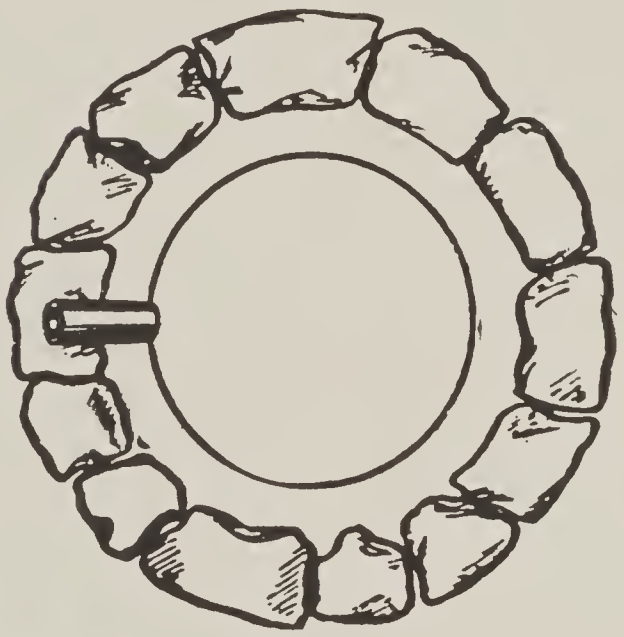
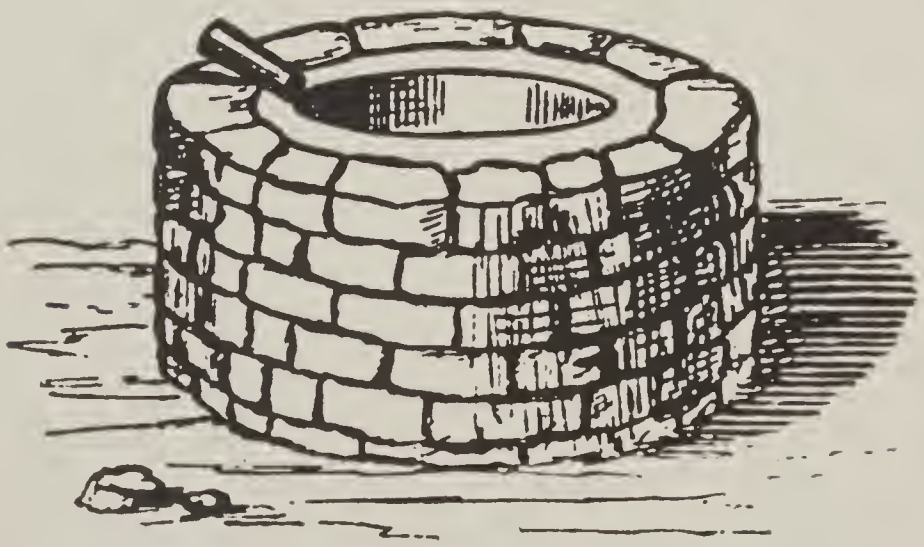
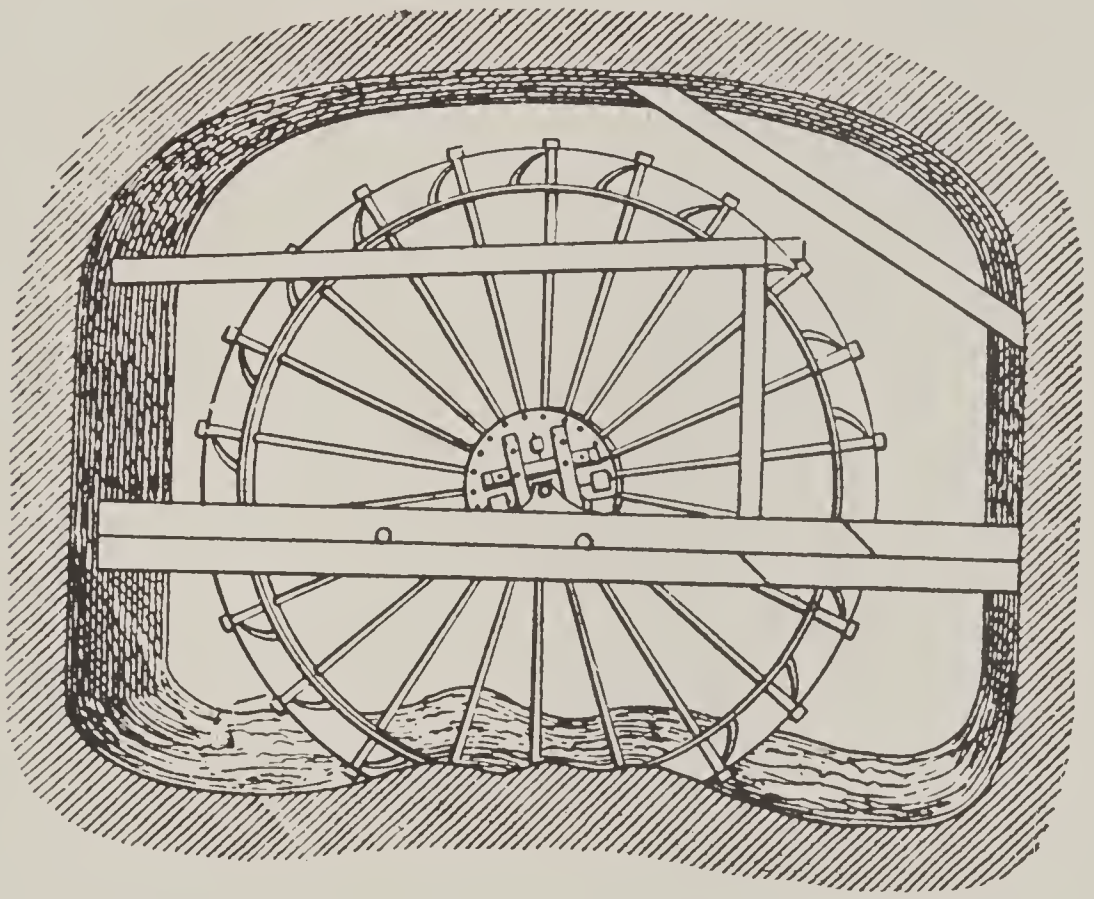


Plan.



A Greek smelting furnace
Reconstructed from remains in Laurion

this time mining engineering was beginning to be developed. This is illustrated by Diodorus' description of their method of overcoming underground streams: "Sometimes at a great depth under the ground they meet with rivers, but by art check the violence of their current; for by cutting trenches under the

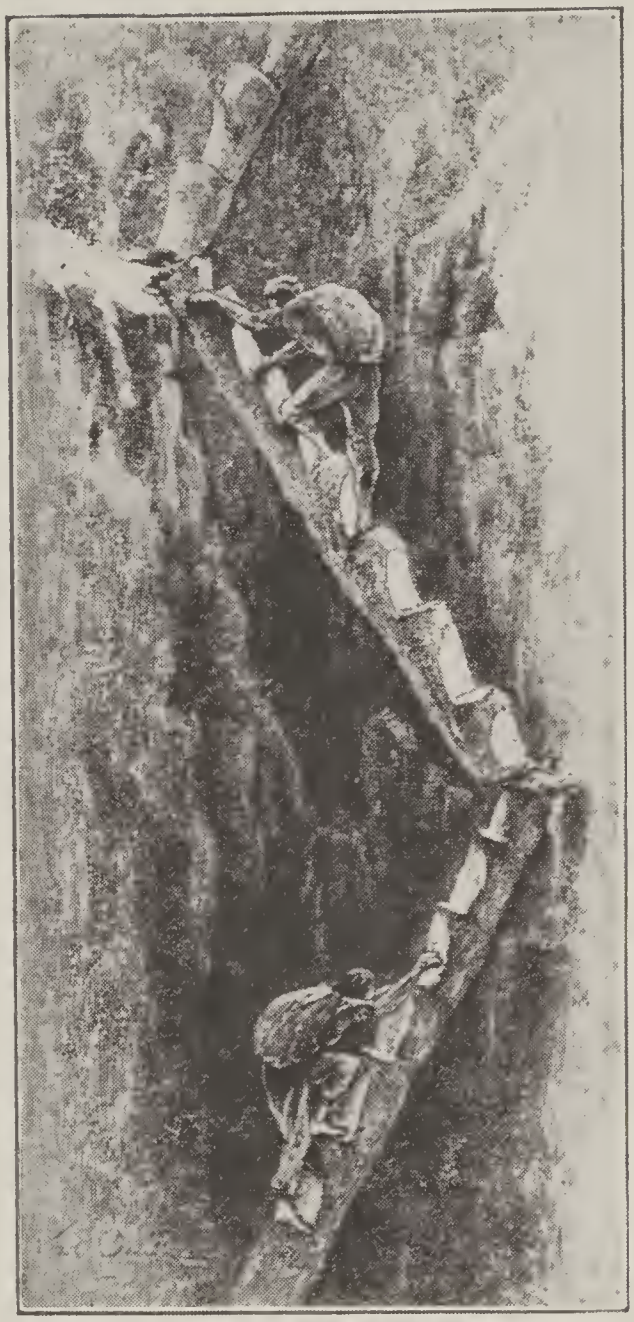


The wheel used for raising water. From remains in Spain

ground they divert the stream . . . and skilfully pump out the flood with machines called Egyptian screws, invented by Archimedes, the Syracusan, when he was in Egypt. . . . For this engine is so ingeniously contrived that a vast quantity of water is cast out with little labor, and the whole flux thrown up from the very bottom of the mine to the surface of the earth."

As under the earlier rulers, the slaves seem to have been worked in the mines without mercy and until they died at their tasks.

In Spain, likewise, according to Diodorus, was found tin. It was common above Lusitania, in the islands opposite Iberia, and much was also transported from Britain into Gaul, the merchants carrying it on horseback to Marseilles.

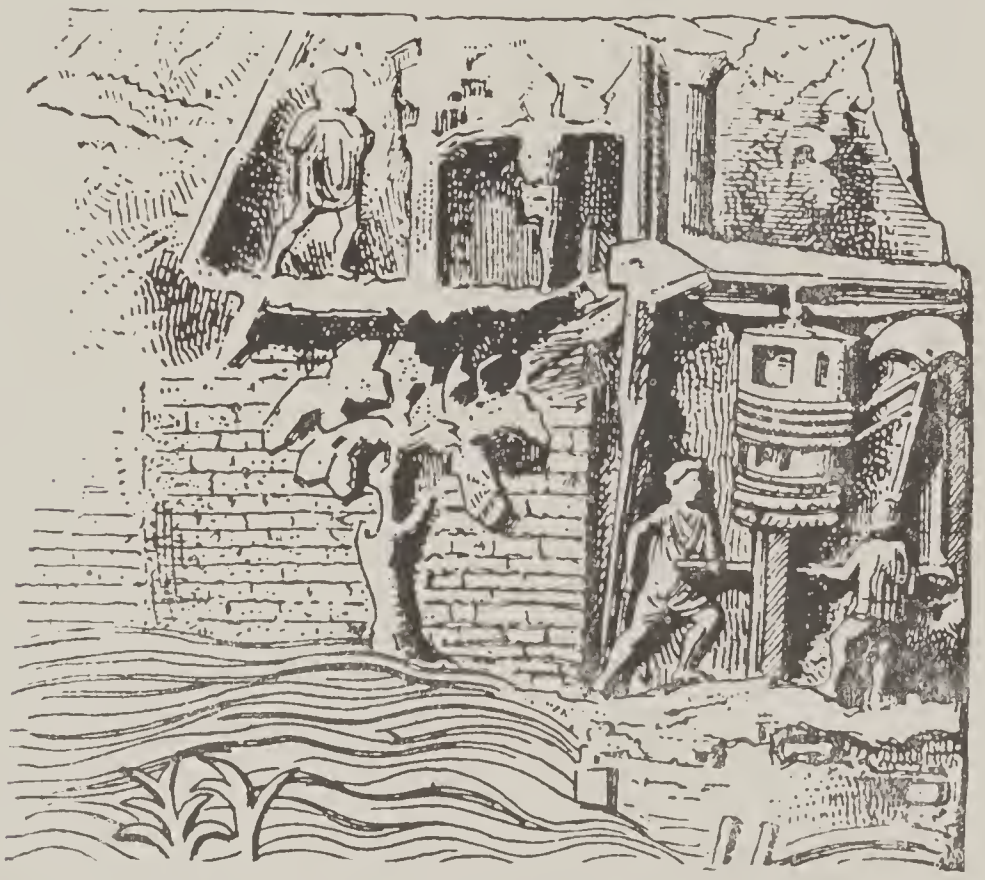


Rude ladders cut from tree trunks. From remains in a Phoenician mine in Spain.

A stamped silver ingot

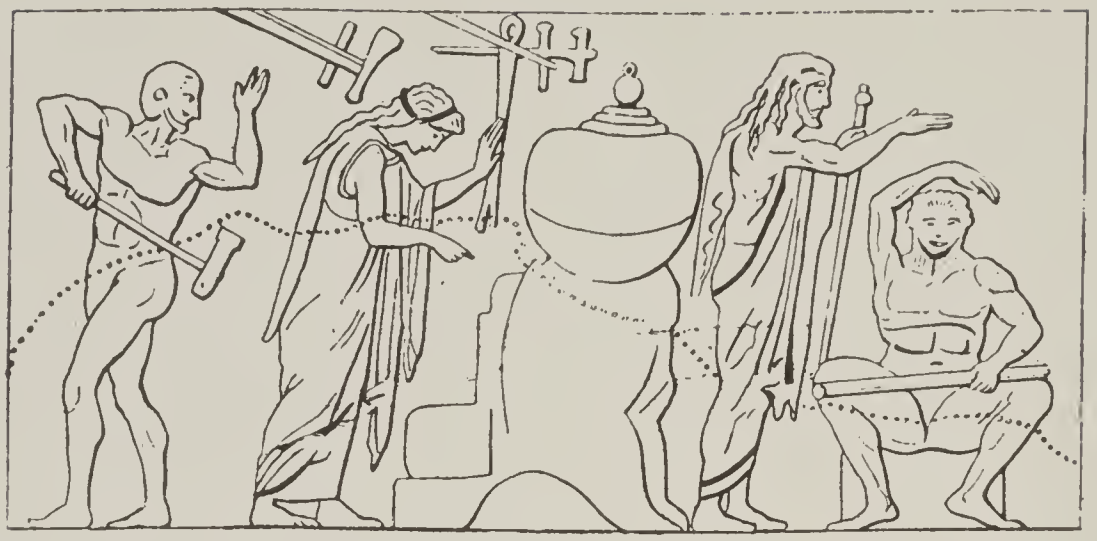
By 30 A. D., according to Strabo, the mines of Laurion were exhausted, but the workmen were still obtaining silver there by committing the old refuse and scoria to the furnace, for the former laborers had carried on the process very unskilfully.

By the first century A. D. mining engineering had become a very practical science among the Romans. Pliny, the Roman scientist, gives a description of the methods of mining gold then



A Roman subterranean machine cutting out rock

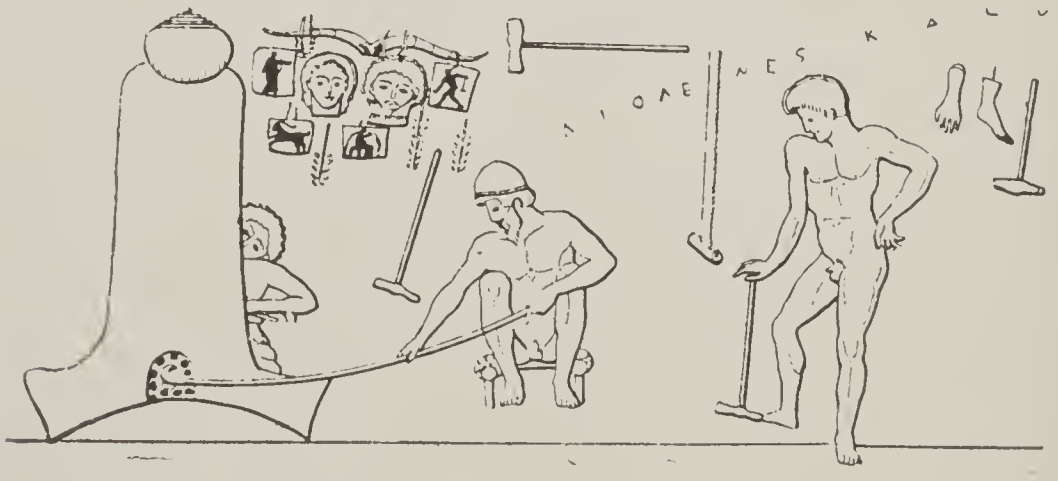
employed, and although it is too long to be quoted, the most important points must be noted. Gold was then procured in three ways, the first of which, Pliny considers, was in the form of dust found in running streams, such as the Tagus in Spain, the Padus in Italy, and the Hebrus in Thrace. The second method was by sinking shafts. The persons in search of gold looked for indications on the surface. When found they washed this earth, or segutilum, as it was called, and from the results conjectured the richness of the vein. Sometimes the gold was found on the surface, as when in the reign of Nero such a vein was discovered in Dalmatia which yielded 50 lbs. of gold a day. But the prospectors were seldom so lucky.



The Greek stack furance with a kettle or crucible on top

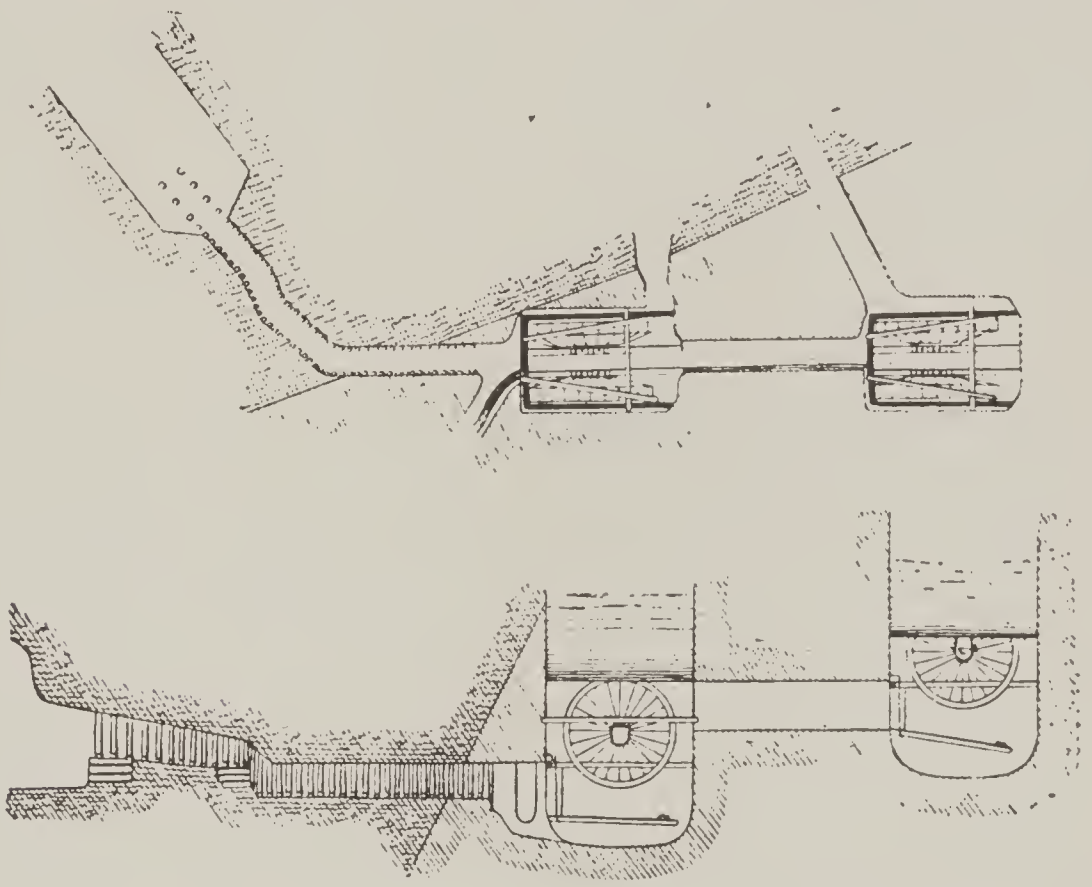
The gold ore mined by means of shafts was known as "canalicium." In the galleries the earth was kept from falling by wooden pillars. The method of obtaining silver and gold from the ore is described by Pliny as follows: "The material extracted is first broken up and then washed. After this it is subjected to the action of fire, and then ground to a fine powder. . . . The silver which becomes disengaged in the furnace is given the name of sudor. . . . In the case of gold the scoria is broken up a second time and melted over again. The crucibles used for this purpose are made of white earth similar to potter's clay, there being no other substance capable of withstanding the strong draft, the action of the fire, and the intense heat of the molten metal."

The third method involved the actual tearing down of a



The stack furnace in a statue maker's place. Note the workmen behind the furnace blowing the bellows

mountain, and Pliny says surpassed the labors of the giants. Galleries were driven to great distances, and mountains were hollowed out by the light of torches, the duration of which set the hours for work, the workmen never seeing the light of day for months at a time. Occasionally the earth caved in and



Roman machines for removing water from mines.
From remains in Spain

crushed the workmen, for which reason arches were left at intervals to support the mountain above, says Pliny.

Sometimes barriers of quartz were encountered, which were broken up by fire and vinegar, or more often, as this filled the galleries with smoke, by means of bruising machines shod with pieces of iron weighing 150 lbs. each. The fragments were passed out by long lines of workmen, each handing pieces on to his neighbor in the dark. Where the quartz appeared too thick, the miners traced along the side of it and flanked it.

Even more obstinate than the quartz was considered the potter's clay mixed with gravel, which was called "gangadia." When the excavating was completed the workers cut away the wooden pillars, beginning with the inmost, which supported the

roof, until the mountain at length caved in, hurling its débris to a distance with a crash, which Pliny says it is impossible for the imagination to conceive.

Washing the débris for the gold required fully as much labor and greater expense. Streams were conducted from still more elevated heights, at a distance in many cases of 100 miles. The fall was kept steep in order to preserve the power of the flow. Sometimes valleys had to be crossed by aqueducts, or obstinate rocks hewed away to make room for troughs of wood. In places this had to be done by workmen suspended with ropes.

Care had to be taken to carry the water only over beds of quartz or pebbles to avoid mud.

At the head of the fall at the very brow of the mountain reservoirs were constructed about 200 ft. square and 10 ft. deep. Usually five sluices 3 ft. square were added, down which, as soon as the flood gates were opened, the water would rush in torrents. Below, on the level ground, trenches wree built to carry the water. In them was placed ulex, a plant somewhat like rosemary, rough and prickly, for arresting any piece of gold that might be carried along. Thus the water in the reservoir was made to wash the débris of the mountain and leave the gold in the trenches. Pliny declared that so many hills were thus washed away and carried to the sea that the shores of Spain were noticeably extended.

A gold ingot with various stamps

III. In the Middle Ages in Europe

Methods Practiced Described by Biringucci—Amalgamation Process Applied to Ores—Treadwheels Used for Hoisting—An Early Mine Car

WHEN the barbarians overran the Roman Empire in the west, the great Roman mines which depended for their operation upon important engineering works were abandoned, and mining in general practically ceased for a century or so. It is doubtful, however, if it was stopped entirely, but where continued it was carried on in a much more primitive way.

A miner of Dieselmount, about 1300 A.D.

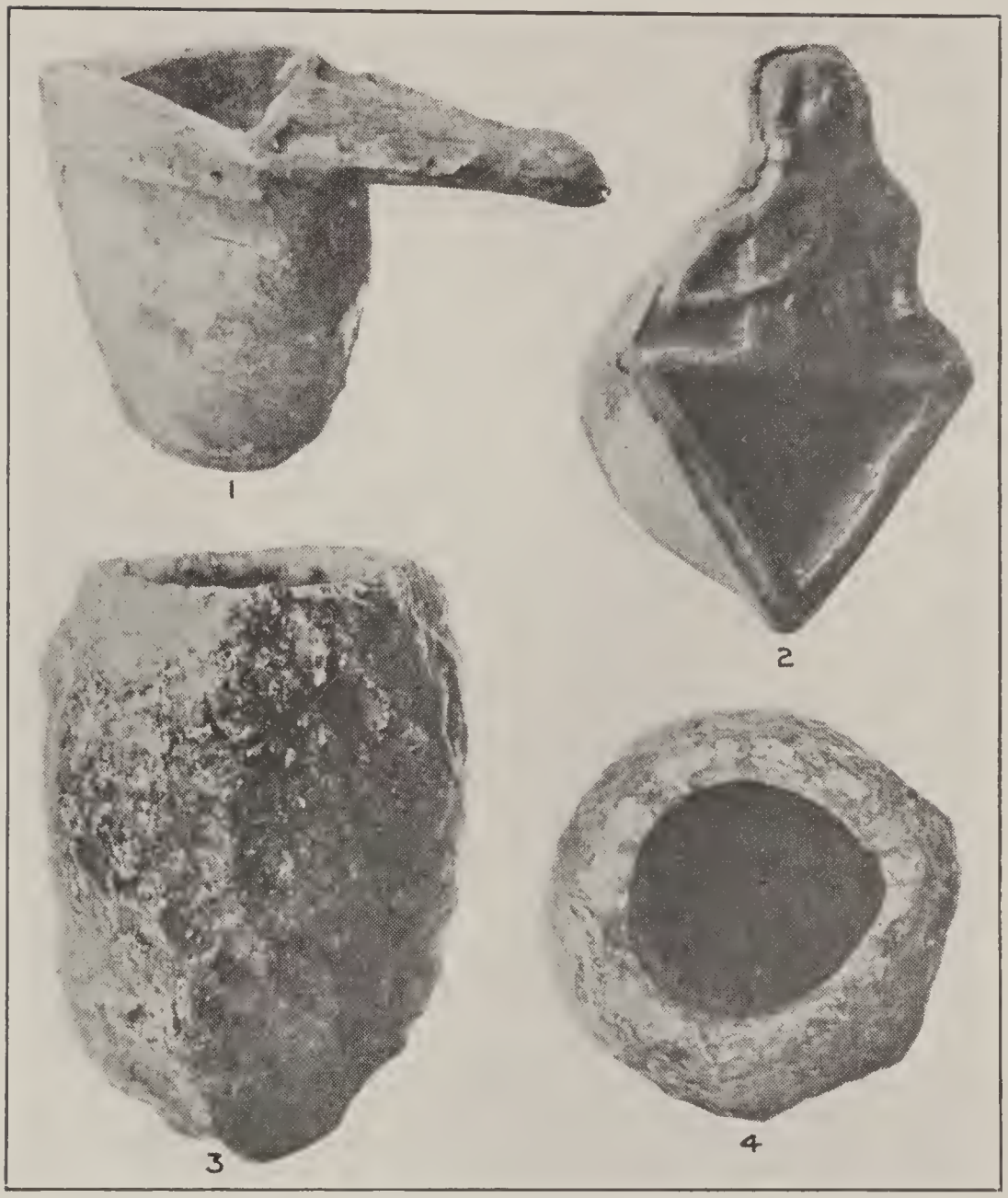
The barbarians themselves, even before they were Christianized, did some mining. The still pagan Avars, for example, about 550 A. D. opened up the electrum mines of Kremnitz, and the silver mines of Chemnitz and Transylvania. In the seventh century the barbarians began to mine silver at Rothansberg, in Bohemia, and in the eighth century the un-Christianized Saxons started mining at Zell and Andreasberg. In England, also, the streams at that time were dug up for tin, though no actual mines for this metal seem as yet to have been dug.

What is probably the remains of a barbarian smelter has been

A miner of the thirteenth century

discovered in the Pyrenees. It was only about 2 ft. in height, the lower half being a cylinder, and the upper half an inverted cone placed over it. Two blast pipes entered about a foot from the bottom. Near by were found lumps of iron weighing from 30 to 35 lbs. Sometimes the furnaces were placed on the edge of a hill where the wind was usually strong. Below the top of the hill was an opening where the wind could enter to blow the fire, while the top of the furnace had another opening above the hill.

It must be remembered, however, that the Dark Ages of Europe were the most brilliant ones of the Mohammedan



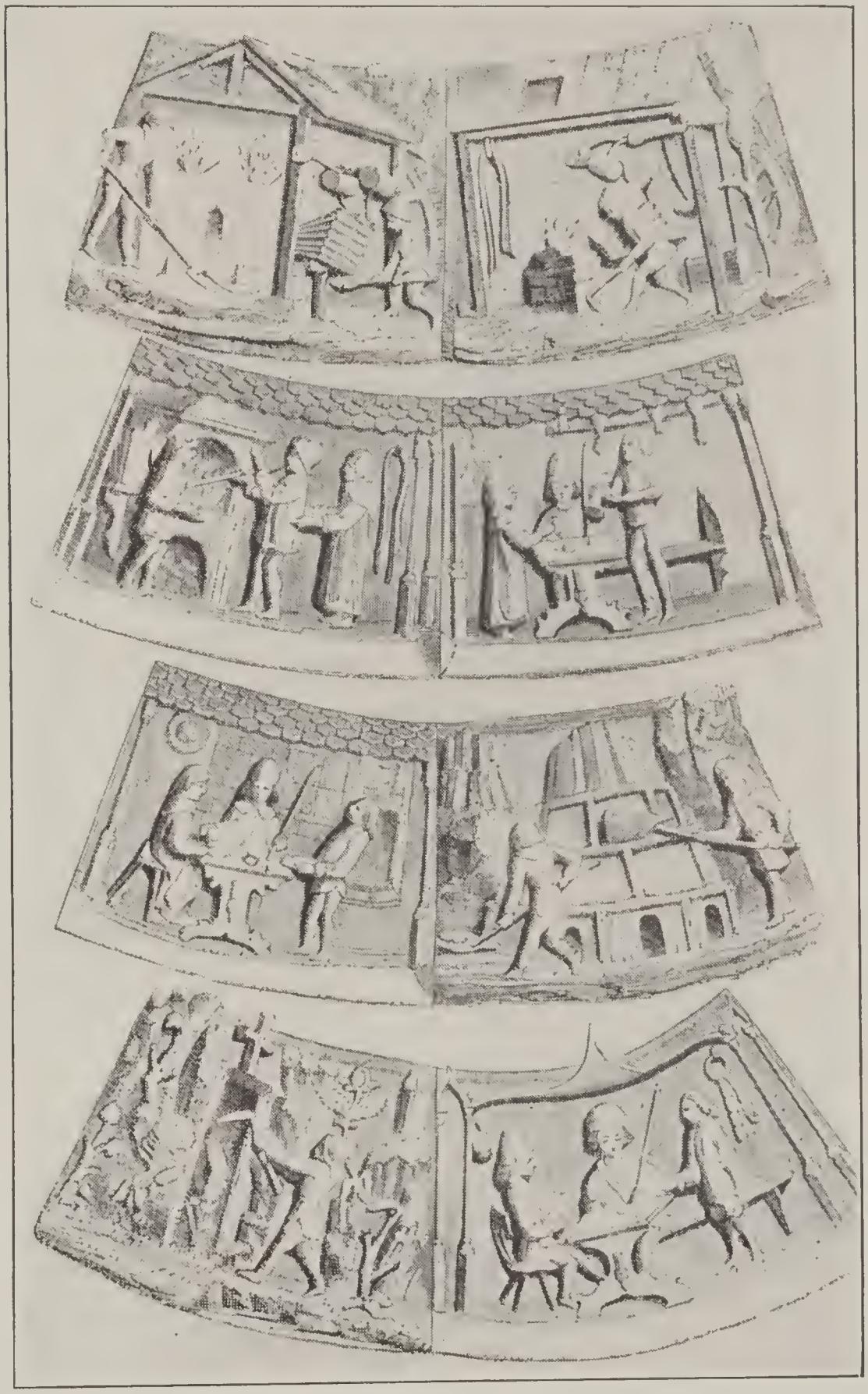
Small crucibles of the early Middle Ages
Fig. 1. Crucible with triangular aperture and horizontal handle, 10 cm. high. Fig. 2. Top view of crucible shown in Fig. 1. On handle is figure of a fiddler. Fig. 3. Crucible from vicinity of Cologne, 14½ cm. high. Fig. 4. Top view of Fig. 3.

realms. In the eighth century, for instance, the Mohammedans worked not only the gold and silver but the iron mines of Spain.

At some unknown date during the early Middle Ages, a highly interesting improvement was made in the blast furnace. This was the Catalan forge, which is reputed to have originated in Catalonia, Spain. Water power was practically inexhaustible in the district, and was applied to blowing the furnace.

The water from a rivulet was caught in a small reservoir just above the furnace, and after the furnace was lighted the water

Mining and smelting scenes of about 1400 A.D.
from a silver vase



Additional scenes from silver vase engraved in Fourteenth or Fifteenth Century

was permitted to run down a pipe at the back of or underneath the furnace. The moving water sucked air down with it, which escaped through a hole in the pipe below the furnace and acted as a constant blast.

One of the first of the mediaeval writers who touched on metallurgy was Theophilus, the monk, about 1100 A. D. In his volume on the various arts he considered the purifying of silver and copper, and the separating of gold from silver or copper. His account of the separating of gold and silver as done by goldsmiths runs as follows:

"Place the scrapings in a small vessel such as gold or silver is melted in. Press a small linen cloth over it so that nothing may be ejected from it by the blast of the bellows. Then melt them by placing it before the furnace. Thereupon lay fragments of sulphur in the molten metal according to the quantity of the scrapings, and carefully stir it with a small piece of charcoal until the fumes cease. Then at once pout out into an iron mold. Beat it upon an anvil gently lest some of the black may fly from it, because this is the silver which the sulphur has burnt. The sulphur consumes none of the gold, but only the silver which it separates from the gold which you carefully preserve. . . . Place all the black upon bone and ashes, and adding lead burn it so that you may recover the silver."

Marco Polo, who visited the Far East about 1300 A. D., mentions a number of gold and silver mines there, but tells nothing of the processes used. In passing, he mentions that in central Asia gold was then worth six times as much as silver. The only operation related to smelting that is mentioned by him is his account of the preparation at Cobinan of an impure oxide of zinc. This runs as follows:

"They have a vein of a certain earth which they put into a great flaming furnace, whilst over the furnace there is an iron grating. The smoke and moisture expelled from the earth adhere to the iron grating and form tutta, whilst the slag that is left after burning is the spodium."

During the Dark Ages the Graeco-Roman cylindrical furnace

was forgotten, but was revived again in the thirteenth century in the stack oven which came into use along the Rhine. This was perhaps 10 ft. tall, with two holes near the bottom for the blast.

The most interesting set of pictures concerning mining and metallurgy is a series engraved on a silver vase by the gold and silversmiths of Gand, France, about 1400 A. D. It consists of sixteen scenes arranged around the vase. In the first scene, a saint's head is pictured over the mouth of the mine, representing no doubt the saint to whom the mine was dedicated in the hopes of warding off misfortune. The second scene represents one miner with his pick just entering the mine, which now has a cross over the top, while another miner is apparently carrying out some of the ore. The third view illustrates the making of wooden props. The fifth scene is remarkable as showing a small car filled with ore, and apparently being pushed along on wooden rails. If this is correct, it is the earliest picture of a car on rails yet brought to light. The sixth scene shows the breaking up of ore, while the next two depict different methods of transporting it.

The ninth to the eleventh scenes, inclusive, represent different furnaces and processes in smelting the ore. Two of these cuts prove that waterwheels were already in use for working the bellows. Another smelting operation is depicted in the fourteenth scene. Here the furnace is higher, and there is no sign of bellows being used. Three of the other views symbolize the business transactions of the silversmiths, while in the remaining view we see the miner once more entering his mine.

Biringucci Describes Mining in Europe

Some conception of mining in Europe may be obtained from the Italian work on pyrotechnics by Biringucci. This was written chiefly to demonstrate the casting and boring of cannon, but leads up to this by means of accounts of mining and metallurgy. In his directions for mining, Biringucci advises that after the signs of ore are discovered, the mine should be begun

A mine and near-by smithy, from Biringucci

not at the top of the hill, as in ancient times, but at the bottom of the hill by means of a passage running horizontally to where it is calculated that the lead is located. Near the entrance of the cave he directed dormitories to be built for the workmen, and a storehouse for their necessities; also a smith's forge where the worn and broken tools could be renewed. After these preliminaries, Biringucci continues:

"Thus in the name of God and good adventure, causing a priest to bless the mountain with all the shops, and to baptize the cave, dedicating it as the manner is to the Holy Trinity, or our Lady, or to some other saint which you have in mind, with the invocation to them to prosper your attempts, you shall with good courage and hope begin to dig the cave."

Where the cave ran through soft material, Biringucci admonished:

"Use all possible diligence in upholding and strengthening the cave well with arches of walls traversed with strong posts of timber after the manner of framed beams, sustained with great and strong piles made of good durable timber of oak or other great trees."

Biringucci suggests shifts of fresh workmen every six or eight hours. In regard to the tools in use he says:

"For the digging of such mines as are found in dead and tender stones, as alabaster and marle, it is requisite apt and strong

Assaying in 1540, from Biringucci

instruments, as great beetles, mattocks and spades of iron, also great and long crowbars of iron to lift great boards; likewise large and small pickaxes, some of iron and some of steel. Furthermore, there should be great mauls with and without handles, and such other tools both of iron and fine hardened steel as the hardness of the stone shall require. . . . Besides these it will also be requisite to have plenty of great baskets, spades, shovels, sleds, hand barrows with and without wheels; and sacks made of raw or untanned hides to carry the fragments out of the cave."

The light was supplied from various materials, as may be seen from the following directions:

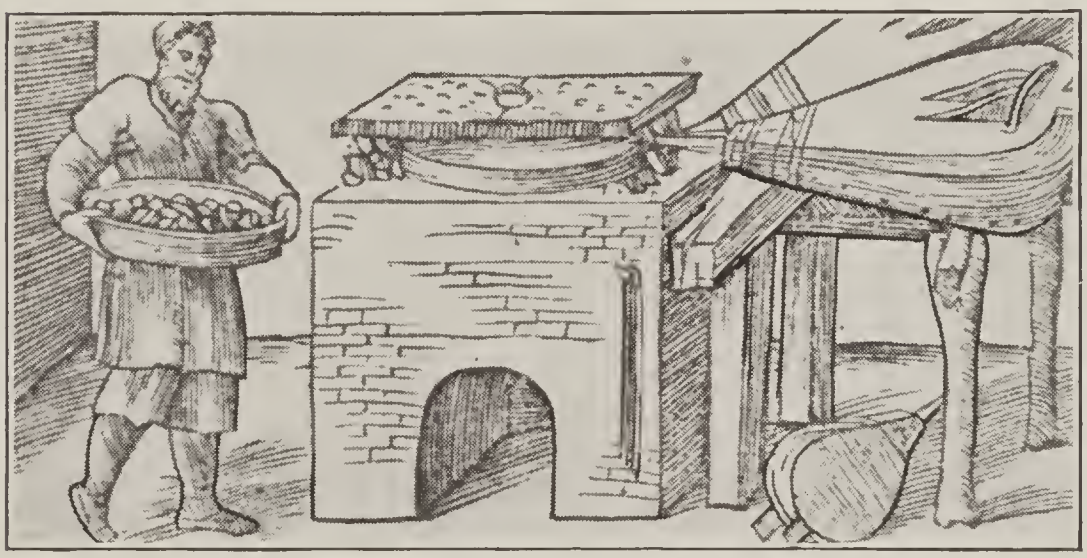
"Have great quantities of unctuous liquors to maintain fire, such as the oils of olives, nuts, linseed, and hempseed; likewise have roots of rotten trees, or animal tallow, or the fat and oil of fishes. For without the light of fire it is not possible for the laborer to work."

Without knowing the reason, the miners of the time recognized the necessity of fresh air to fire, for Biringucci added:

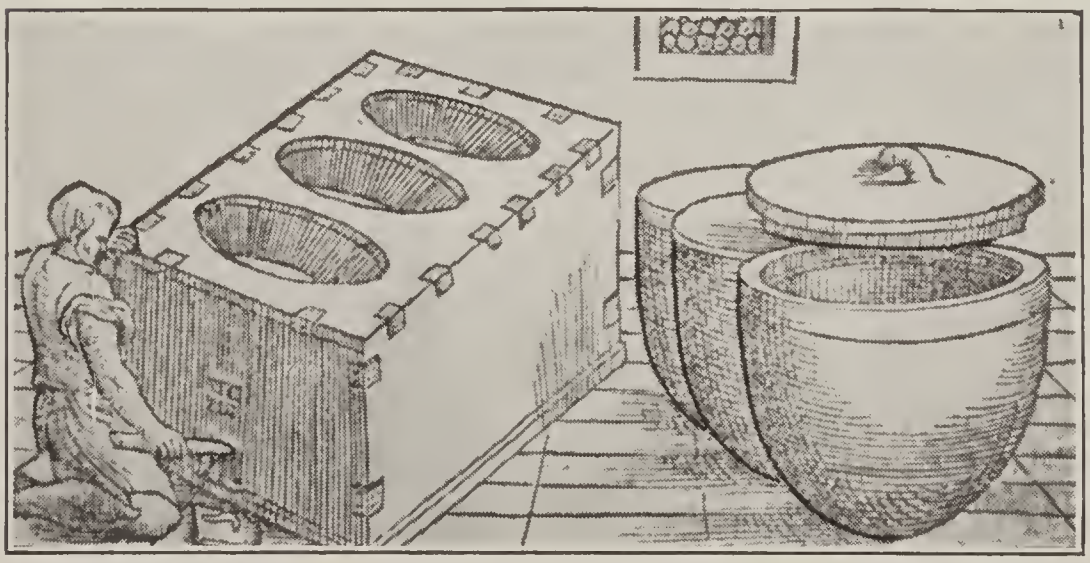
"Nor can any fire be maintained in the cave except it receive the air through some 'respiracle' or breathing place, by means of a funnel or trunk of wood, or such other open pipe whereby the air may be conveyed into the cave."

Several remarkably interesting cuts illustrating mining in

Grinding ore in amalgamation process, from Biringucci

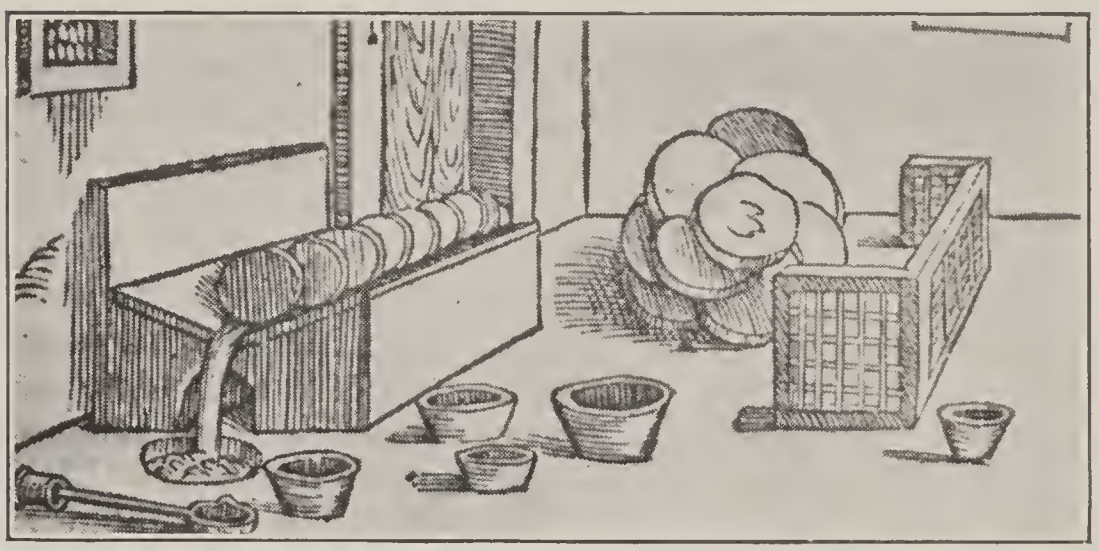


A silver furnace, 1540, from Biringucci

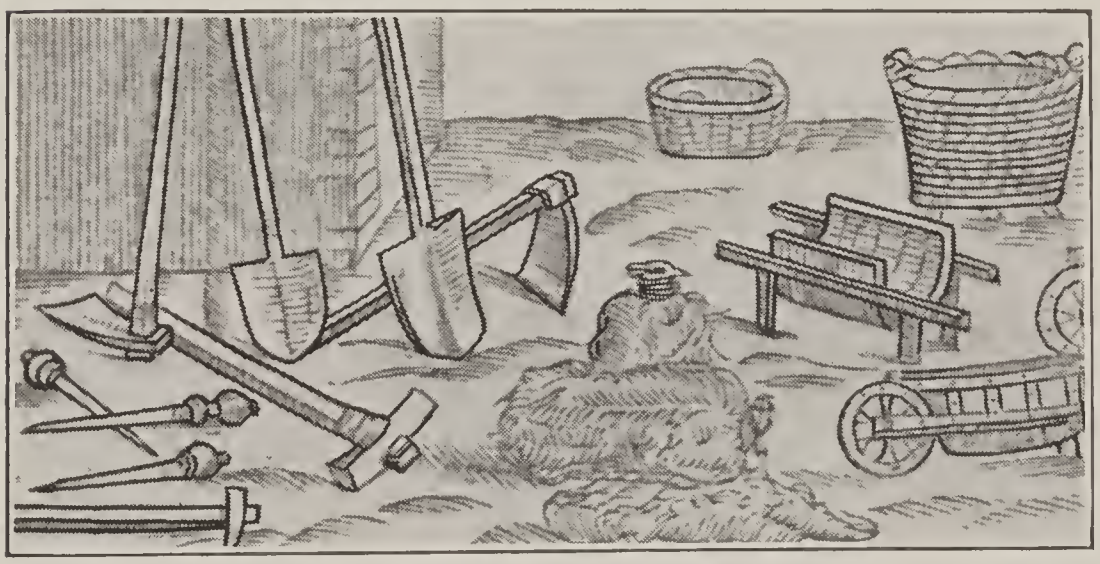


Furnace for quicksilver, from Biringucci

Preparing to reduce quicksilver, from Biringucci



Liquating furnace and cupellation cups, 1540



Miners' tools, from Biringucci

the middle of the sixteenth century are contained in the history of the northern countries, written in Latin by the Archbishop of Upsala. One of the cuts shows a large treadwheel in use at the top of the mine for hoisting the metal or the miners. Such treadwheels were in use in Roman times, but it is interesting to find them adopted as far north as Sweden.

In another cut may be seen a cave at the bottom of the shaft. On the left a miner is at work with his mallet and wedge. At the right is depicted the devil or one of the evil spirits of the mine causing a cave-in. To the artist this was no fanciful conception, for at the time it was universally believed that the mines were inhabited by demons, who caused the accidents which inevitably took place.

In regard to smelting Biringucci is even more informative of the advance made at that date.

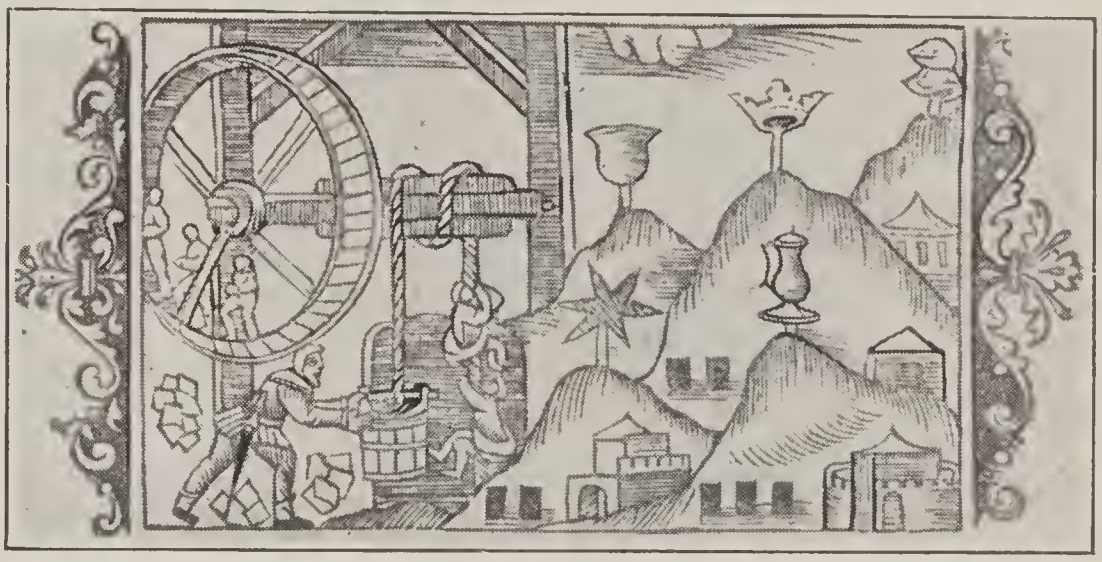
The amalgamation of gold and quicksilver was known to the Romans, and was used by their goldsmiths in refining gold. Pliny, for example, wrote of it:

"All substances float upon the surface of quicksilver, with the exception of gold, this being the only substance that it attracts to itself. Hence it is, that it is such an excellent refiner of gold; for on being briskly shaken in an earthen vessel with gold, it rejects all the impurities that examider with it. When once it has thus expelled all these superfluities, there is nothing to do but to separate it from the gold: to effect which it is poured out upon skins that have been well towed, and so exuding through them like a sort of perspiration, it leaves the gold in a state of purity behind."

First Description of Amalgamation Process Applied to Ores

But the amalgamation process for separating gold from its ores, and especially for smelting silver, does not seem to have been used in ancient times, and the account of it by Biringucci is thought to be the earliest. His account is therefore worth repeating at least in part:

"He was surely endowed with much useful and novel genius, who invented the quick method of extracting metal out of the sweepings from those arts that work gold and silver, from the refuse of those materials and also from certain ores themselves, without the labor of fusing, but by the sole means and virtue of mercury. To effect this a large basin is first constructed of stone or timber and walled, into which is fitted a millstone made



Swedish mine, sixteenth century, from Archbishop of Upsala. Note treadwheel for hoisting

to turn like that of a mill. Into the hollow of this basin is placed matter containing gold, well ground in a mortar and afterwards washed and dried; and, with the above-mentioned millstone, it is ground while being moistened with vinegar, or water in which has been dissolved corrosive sublimate, verdigris and common salt. Over these materials is then put as much mercury as will cover them; they are then stirred, for an hour or two, by turning the millstone, either by hand or horsepower, according to the plan adopted, bearing in mind that the more the mercury and the materials are bruised together, by the millstone, the more the mercury may be trusted to have taken up the substance which the materials contain. The mercury, in this condition, can then be separated from the earthy matter by a sieve, or by washing, and thus you will recover the auriferous mercury. After this, by driving off the mercury by means of a flask, or by passing it through a bag, there will remain, at

Smelting arrangements, from Archbishop of Upsala

the bottom, the gold, silver, or copper, or whatever metal was placed in the basin under the millstone to be ground.

"Having been desirous of knowing this secret, I gave, to him who taught it to me, a ring with a diamond worth 25 ducats, he also required me to give to him the eighth part of any profit I might make by using it. This I wished to tell you, not that you should return the ducats to me for teaching you the secret, but in order that you should esteem it all the more and hold it dear."

Biringucci also describes the cementation process for separating gold and silver. This consisted in brief of interlaying the metal with powdered brick, common salt, and occasionally a

Interior of Swedish mine, sixteenth century.
Note evil mine demon at right

little green vitriol, and then baking in the furnace for twenty-four hours. But as this process was far less important than the amalgamation method, the more complete description may be omitted.

Important variations in the furnace, of which Biringucci seems to be the first to make mention, were the reverberatory and liquidation types which he recommended for use in treating ores and metals in certain cases.

This brings us in Europe to the middle of the sixteenth century, but in the meantime mining had already begun on an important scale in the newly discovered Western Hemisphere.

IV. In Sixteenth Century America

Practices of the Incas and Improvements by the Spaniards—The Discovery of Potosi—Acosta Describes the Amalgamation Process and the Use of Quicksilver in Smelting Silver

WHEN the Spaniards discovered Central America, Mexico, and Peru they found the natives using gold much as they did copper, and valuing it little if any more highly. Silver also was in use, but the natives knew nothing of iron, and when first made presents of iron

Indians smelting with blowpipes, from Benzoni

hatchets, and other tools, valued them more highly than they did gold because of their greater usefulness. The Incas had pots, cups, flagons, and even chairs and litters of gold, to say nothing of many images of their gods. This was not because they valued gold more highly, but because it was capable of being easily worked into such forms.

The methods of mining were very simple. Peter Martyr says that in getting gold from streams the Indians simply

gathered up the sand in their hands, and shifted it from one hand to the other until most of the sand flowed out.

The Incas smelted by means of furnaces without any chemical processes. They used blowpipes, though not bellows, avoiding the employment of the latter by placing many of their furnaces on the side of a hill where the wind would blow the fire. The blowpipes were used more for the small furnaces in which the metal was melted so that it might be cast.

Spain, it will be remembered, was the greatest source of precious metals in ancient times, and the Spaniards had no sooner discovered America than they began to look for gold and silver there. They started mining on the Isthmus, at Darien, about 1514. Oviedo, who wrote in 1526, said that he had been for twelve years "surveyor of the melting shops pertaining to the gold mines of the main land."

At first, the king's share was one-fifth, but in 1526 it was temporarily reduced to one-tenth of the products of the mine and by successive re-enactments this continued to be the royal tithe. At the same time mining was made open to both Spaniards and natives, and attempts, though not always successful ones, were made to protect the natives. Slaves were early introduced, and formed a distinct class from the Indians themselves.

Oviedo wrote that in mining on land, the dirt was carried from the mine in trays to the stream where it was delivered to washers. These were for the most part Indian women, who were wont "to sit by the water's edge with their legs in the water even up to the knees," and thus pan the pay dirt.

But more important than the gold mines discovered by the Spaniards in Central America, Mexico, and Peru were those of silver. Even before the discovery of America the Incas made the mines at Porco produce large quantities of silver. A tremendous impetus to silver mining was given by the discovery of silver at Potosi, Peru, in 1545.

The story is that this came about as follows: A Peruvian by the name of Gualpa, who worked in the mines of Porco, went

hunting one day, and it chanced that the game ran up the steep mountain of Potosi. He attempted to follow it by taking hold of one scrub after another, but eventually his weight pulled a bramble, called *quinua*, out by the roots. It seemed very heavy, and looking down he saw a great lump of silver hanging

Spaniards forcing Indians to mine for them

to it. Examining the hole he discovered a large vein of silver ore, which upon being smelted at his home he found to be of the highest grade he had ever known. He worked his mine secretly for some time, but at last his evidently increasing wealth excited the suspicion of his neighbor, Guanca, who forced him to disclose the secret, and started working a near-by vein. As the metal did not come from this so easily, Guanca told his Spanish master, Vilaroel, who in turn registered the mine, and, in accordance with the mining law, obtained several rods to work for himself.

The best description of sixteenth century mining in America is given by Acosta, who after spending a number of years in Peru, returned to Spain in 1587, and in 1590 wrote in Spanish his "Natural and Moral History of the Indies."

According to Acosta, the most famous gold was that of

Incas smelting and casting

Carovaya, in Peru, and Valdivia, in Chile. An idea of the quantity of gold produced may be gathered from his statement:

"In the fleet in which I came to Spain, which was in the year 1585, the declaration of the mainland was twelve cassons or chests of gold, every casson weighing at least four *arrobas*, that is a hundred weight, and 1,056 marks from New Spain which was for the king only, besides that which came registered for merchants and private men, and much that came unregistered."

Since the mines of Potosi were of such tremendous importance, Acosta paused to give quite a description of them, from which we may abstract the following account:

"The rock of Potosi contained four principal veins running north and south, besides various lesser veins running from the main lodes like branches on a tree. By 1585 the mines were deep for that period. In one vein at Potosi were reckoned seventy-eight mines which were 100 fathoms deep, and a few which were 200 fathoms. In another vein were twenty-four shafts, some from 70 to 80 fathoms deep. To facilitate working at this depth, the Spaniards constructed tunnels called *socavones*, which were begun at the foot of the mountain, and ran horizontally to meet the vein. These were a fathom in height and eight feet in width. One of these tunnels was begun in 1556, and required twenty-nine years to construct. In 1585 this was driven 3,500 ft. into the mountain, and met the mine shaft 135 fathoms below the top. There were already nine tunnels completed and others begun."

Acosta's description of the work in the mine is too vivid not to be quoted:

"They labor in these mines in continual darkness and obscurity, without knowledge of day or night. And forasmuch as those places are never visited with the sun, there is not only a continual darkness, but also an extreme cold, with so foul an air contrary to the disposition of man, that such as newly enter are sick as they are at sea. The which happened to me in one of these mines, where I felt a pain at the heart, and heating of the stomach. Those that labor therein use candles to light them, dividing their work in such sort, as they that work in the day rest by the night, and so they change. The metal is commonly hard, and therefore they break it with hammers; splitting and hewing it by force as if they were flints. Afterwards they carry up this metal upon their shoulders, by ladders of three, branches made of neats leather twisted like pieces of wood which are crossed with staves of wood, so that by every one of these ladders they mount and descend together. They are ten *estados* long apiece, and at the end of one, begins another of the same length, every ladder beginning and ending at platforms of wood where are seats to rest them like unto galleries for that

there are many of these ladders to mount by, one at the end of another. A man carries ordinarily the weight of two *arrobas* of metal upon his shoulders, tied together in a cloth in manner of a skippe, and so mount they three and three. He that goes before carries a candle tied to his thumb, for, as it is said, they have no light from heaven, and so they go up the ladder holding it with both their hands; to mount so great a height which commonly is above 150 *estados*—a fearful thing which breeds an amazement to think upon it, so great is the desire of silver, that for the gain thereof men endure any pains."

Acosta also gives an interesting account of the earliest known American smelting. He says the Indian method was by dissolving the metal by fire. "To this end," says Acosta, "they built small furnaces where the wind commonly blew, and with wood and coal made their refining the which furnaces in Peru they called *huayras*."

The Spaniards had at first also used such *huayras*, which were best for refining the richest ores. Later they learned to use the process of amalgamation with quicksilver. The method there employed is described by Acosta as follows:

"They first beat and grind the metal very small, with the hammers of the machinery, which beat this stone like unto tan milles, and being well beaten they 'searce' it in a copper 'searce,' making the pouder as small and fine as if it were horse hair; these 'searces' being well fitted, do sift 30 quintals in a day and a night; then they put the pouder of the metal into the vessels upon furnaces, whereas they anoint it and mortify it with brine, putting to every 50 quintals of pouder, 5 quintals of salt. And this they do for that the salt separates the earth and filth, to the end the quicksilver may the more easily draw the silver unto it. Afterwards they put quicksilver into a piece of holland and press it out upon the metal, which goes forth like a dew, always turning and stirring the metal, to the end it may be well incorporated.

"Before the invention of these furnaces of fire, they did often mingle their metal with quicksilver in great troughs, letting

it settle some days, and did then mix it and stir it again, until they thought all the quicksilver were well incorporate with the silver, the which continued twenty days and more, and at the least nine days.

"Since they discovered, as the desire to get is diligent, that

Llamas carrying silver bars, sixteenth century

to shorten the time fire did much help, to incorporate silver the sooner with quicksilver, they invented these furnaces,whereon they set vessels to put in their metal with salt and quicksilver, and underneath they put fire by little and little in furnaces made for the nonce underneath; so that in five or six days the quicksilver is incorporate with the silver.

"And when they find that the mercury hath done his part, and assembled all the silver, leaving nothing behind, but is well imbrued, as a sponge doth water, dividing it from the earth, lead, and copper, with which it is engendered, then they separate it likewise from the quicksilver, the which they do in this

sort; they put the metal in caldrons, and vessels full of water, where with certain wheels they turn the metal round about, as if they should make mustard, and so the earth and dross go from the metal with the water that runs away. The silver and quicksilver as most ponderous remaining in the bottom, the

Incas smelting and forging, from De Bry

metal which remains is like unto sand. Then they take it out and wash it again in great platters of wood, or keelers full of water, still drawing the earth from it, until they leave the silver and quicksilver well cleansed. There slips away also some small portion of silver and quicksilver with the earth and dross, which they call washings, the which they wash again and draw out the remainder.

"When the silver and quicksilver are clensed and begin to shine, and that there remains no earth, they put all the metal

into a cloth, which they strain out very forcibly, so that all the quicksilver passeth out, being not incorporate with the silver, like to a mark of almonds pressed to draw oyle. And being thus pressed the remainder contains but the sixth part in silver, and five in mercury. So if there remains a mark of threescore

Potosi and one of its smelters

pounds, ten are of silver, and fifty of mercury. Of these marks they make *pinas*, as they call them, like pine apples or sugar loaves, hollow within, which they commonly make of a hundred pound weight.

"Then to separate the silver from the quicksilver, they put it into a violent fire which they cover with an earthen vessel, like to the mold of a sugar loaf, or unto a capuchon or hood, the which they cover with coals, and set fire unto it; whereby the quicksilver exhales the smoke, which striking against the capuchon of earth, thickens and distills, like unto the smoke of a pot covered; and by a pipe, like unto a limbecke, they receive

the quicksilver which distills, the silver remaining without changing the form, but in weight it is diminished five parts of that it was, and is spungious, the which is worthy of observation. Of two of these loaves they make one barre of silver, in weight 65 or 66 marks; and in this form they carry it to the

Interior of silver mine in Peru, sixteenth century

touch, custom, and mark. Silver drawn with mercury is so fine, that it never abates of two thousand three hundred and fourscore of alloy."

Both stamp mills and grinding mills were used at Potosi, and they were driven by either horsepower or waterpower. It rained only during the winter there, and the rain had to be stored in reservoirs for use in the summer months. If necessary, however, the ore could be carried three or four leagues to Tarapaya, where power was furnished by a river.

The use of quicksilver in smelting was of course not known to

the Incas, but they did have mines of vermilion, from which they made paint for decorating themselves. A Portuguese named Henrique Garces, who had known of vermilion in Castile, suspected this to be the same as that from which mercury was extracted, and upon examining the mine, found this to be the fact.

The application of quicksilver to smelting in Peru was credited to Fernando de Velasco in 1571. Its success naturally led to a great demand for quicksilver. The smelting of this is described by Acosta as follows:

"Let us now speak of how they draw out quicksilver, and how they refine silver therewith. They take the stone or metal where they find the quicksilver, which they put into the fire in pots of earth well luted, being well beaten, so that this metal or stone coming to melt by the heat of the fire, the quicksilver separates itself, and goes forth in exhalation, and sometimes even with the smoke of the fire, until it encounters some body where it stays and congeals, and if it pass up higher, without meeting of any hard substance, it mounts up until it be cold, and then, congealed, it falls down again. When the melting is finished, they unstop the pots and draw forth the metal, some times staying until it be very cold, for if there remained any fume or vapor, which should encounter them that unstopped the pots, they were in danger of death, or to be benumbed of their limbs, or at least to loose their teeth."